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Kleitsch

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(54) **CONTROL VALVE WITH VARIABLE PRESSURE RELIEF**

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See application file for complete search history.

(71) Applicant: **Caterpillar Inc.**, Peoria, IL (US)

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(72) Inventor: **Andrew J. Kleitsch**, Shorewood, IL (US)

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(73) Assignee: **Caterpillar Inc.**, Peoria, IL (US)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 387 days.

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Primary Examiner — Michael Leslie

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(74) *Attorney, Agent, or Firm* — BakerHostetler

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(52) **U.S. Cl.**

CPC **F15B 15/00** (2013.01); **F15B 13/024** (2013.01); **F16H 61/4017** (2013.01)

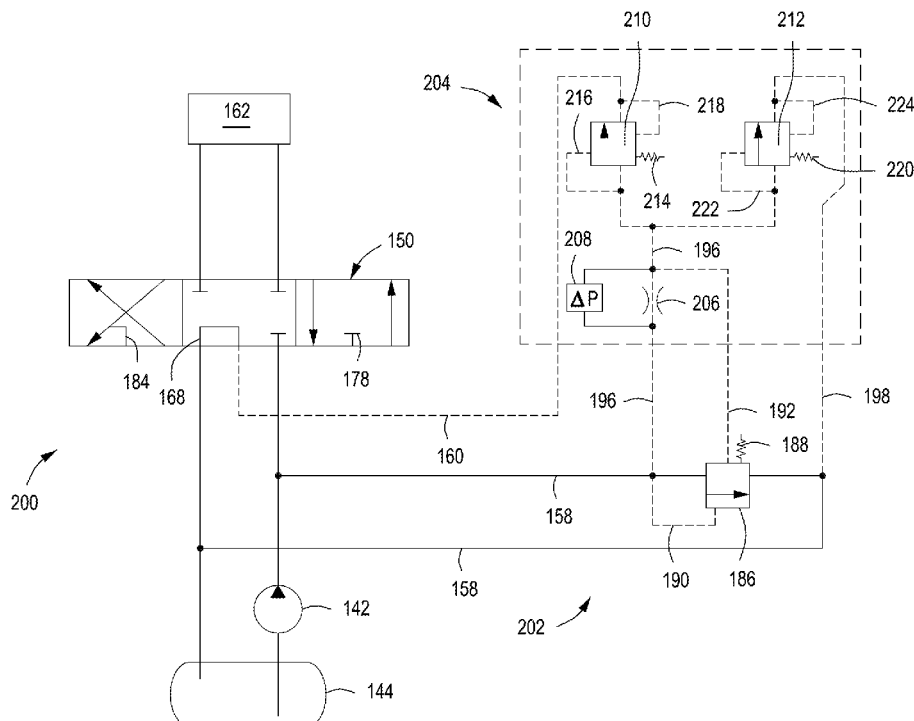
(58) **Field of Classification Search**

CPC F15B 13/024; F16H 61/4017; F16H 61/4052; F16H 61/4061

(57) **ABSTRACT**

A hydraulic system and method of controlling hydraulic pressure are disclosed. The hydraulic system includes a pump fluidly coupled to a reservoir that contains hydraulic fluid, a control valve fluidly coupled to the pump, the control valve being selectively movable between at least two positions, a relief valve fluidly coupled to the pump via a relief conduit, the relief valve operable to flow hydraulic fluid from an outlet of the pump to the reservoir, and a variable pressure setpoint module fluidly coupled to the relief valve and the control valve. The variable pressure setpoint module being operable to open the relief valve in response to at least two pressure setpoints depending on a position of the control valve.

20 Claims, 5 Drawing Sheets



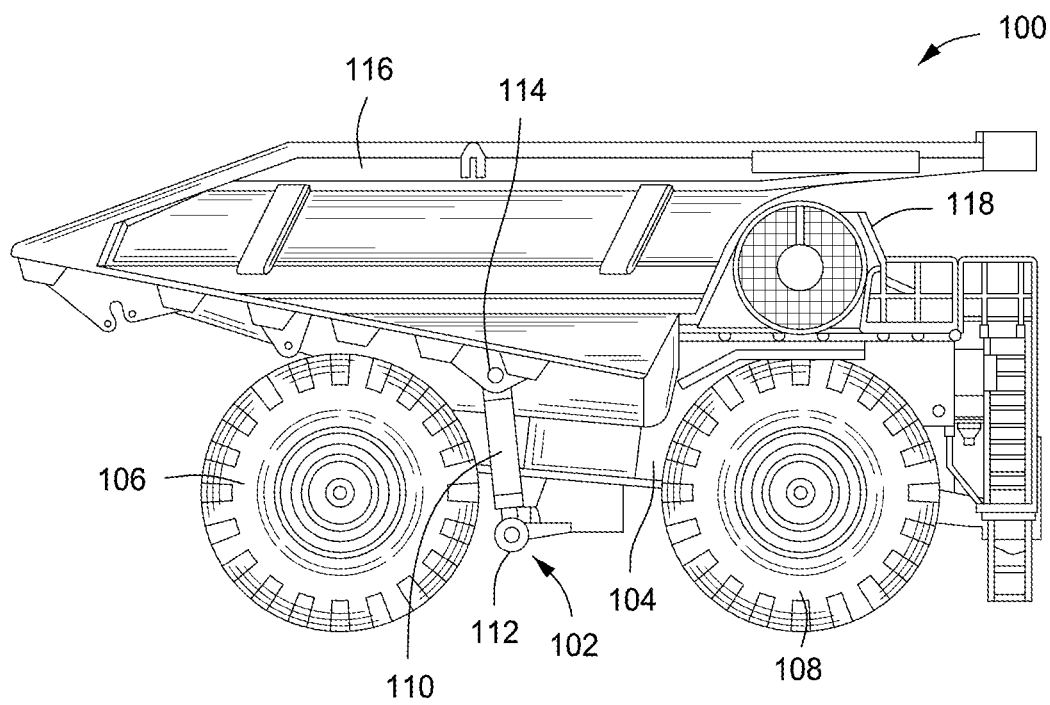


FIG. 1

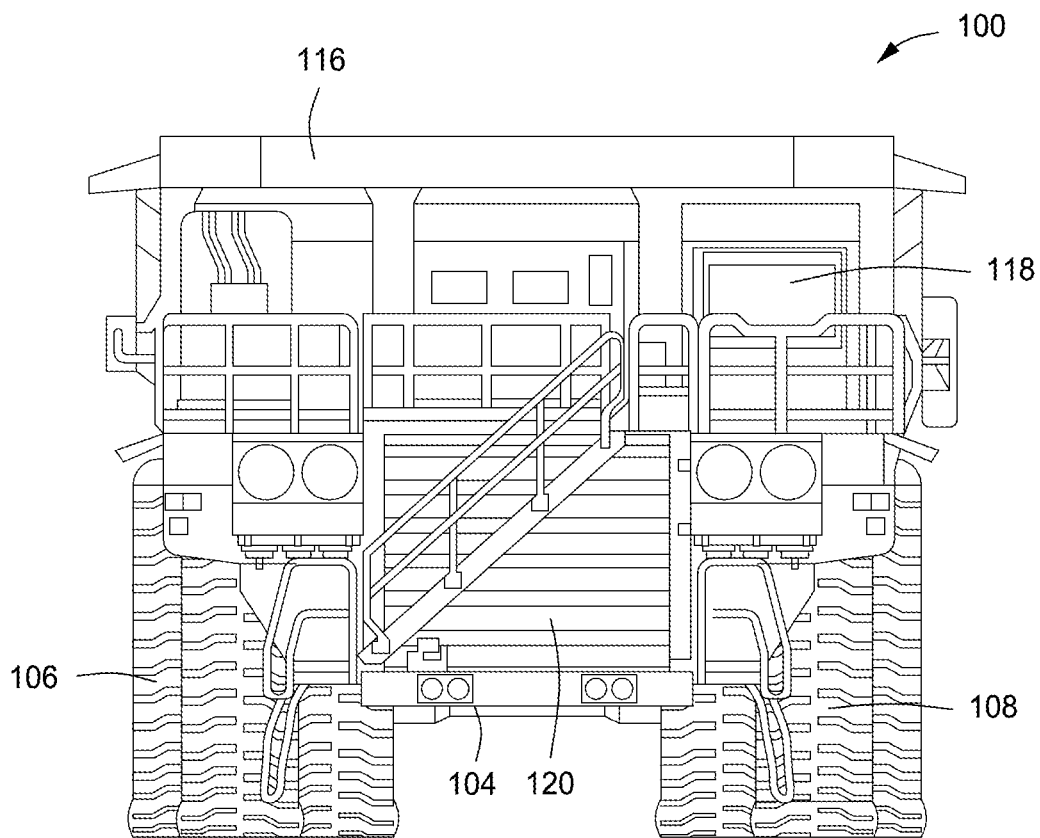
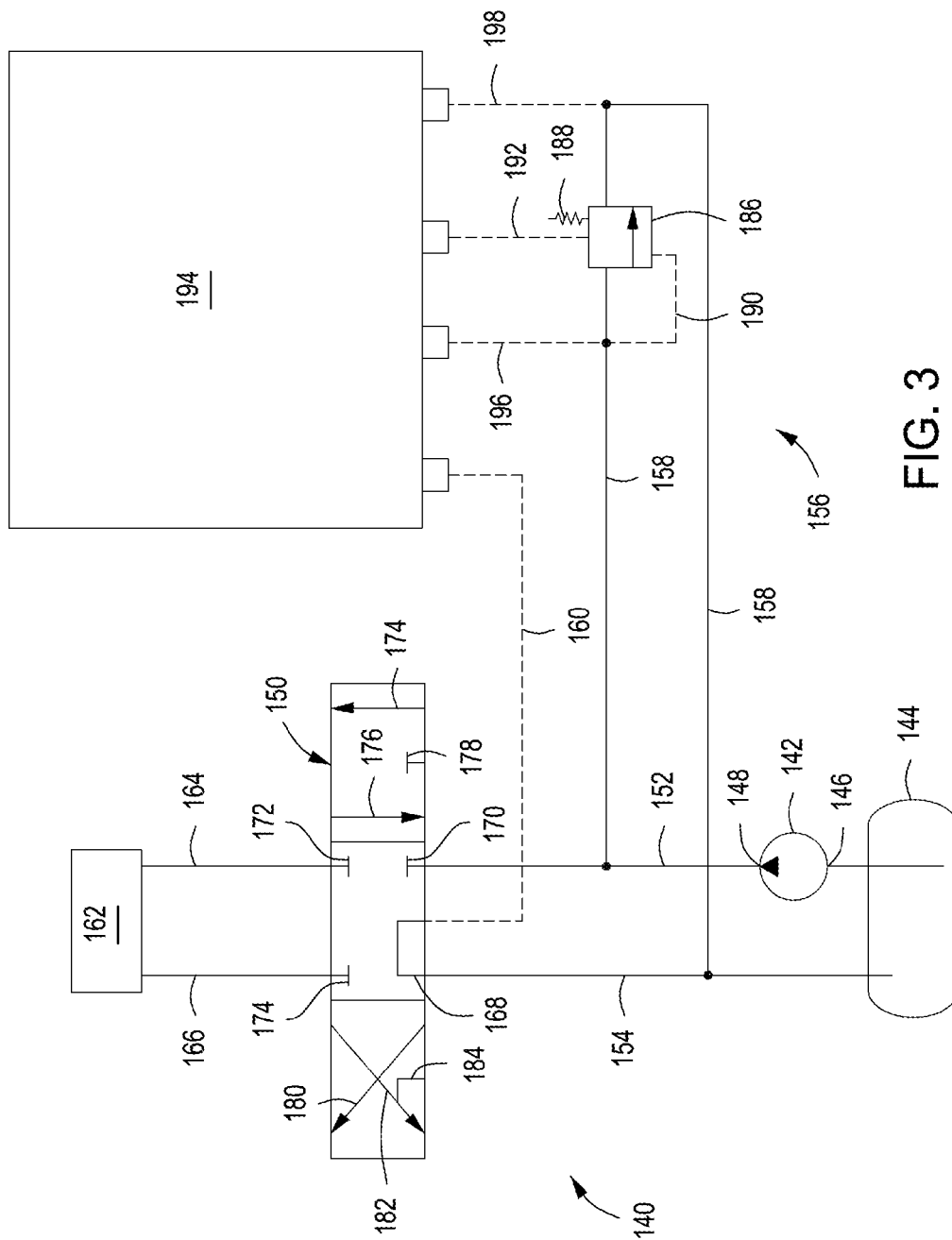


FIG. 2



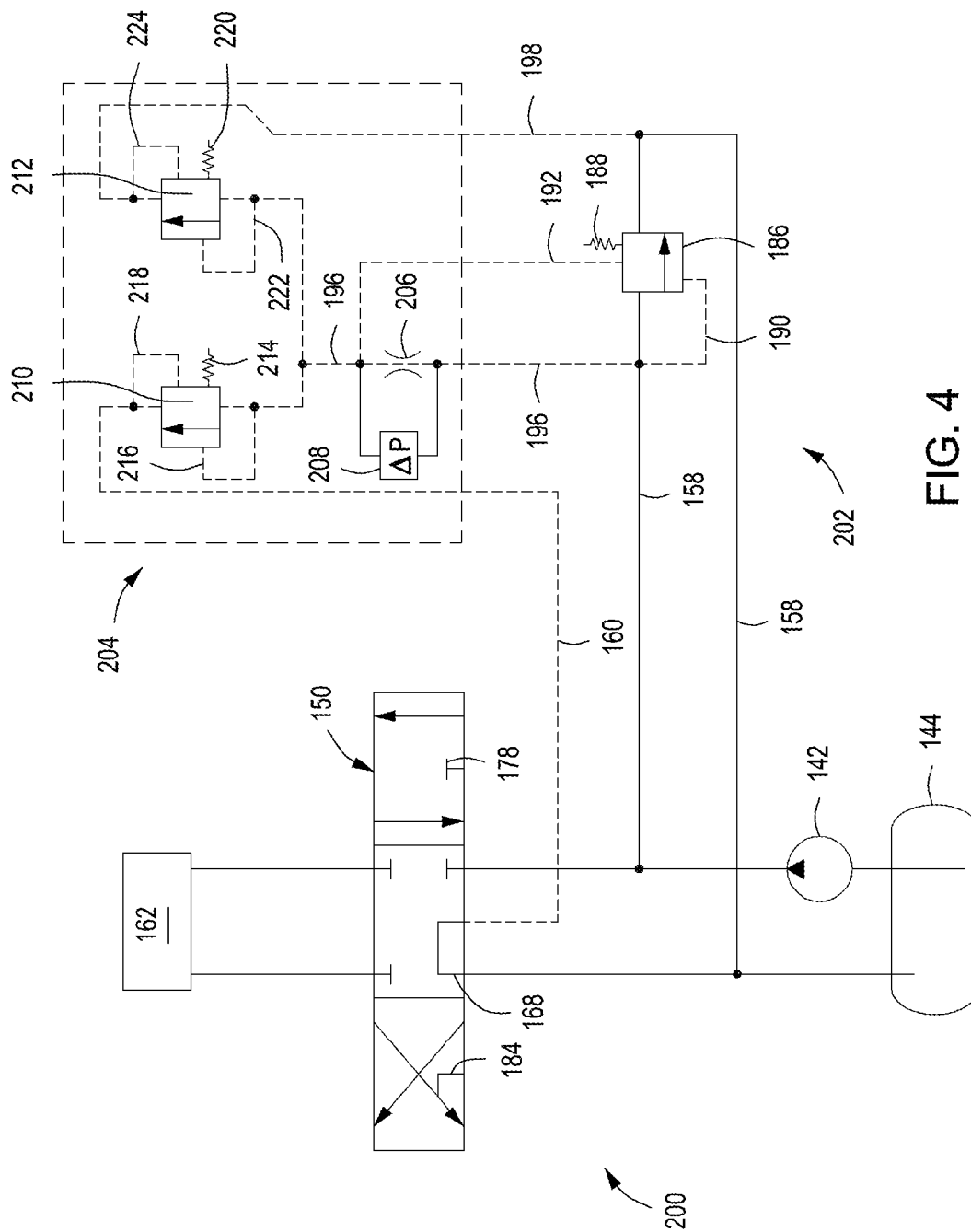


FIG. 4

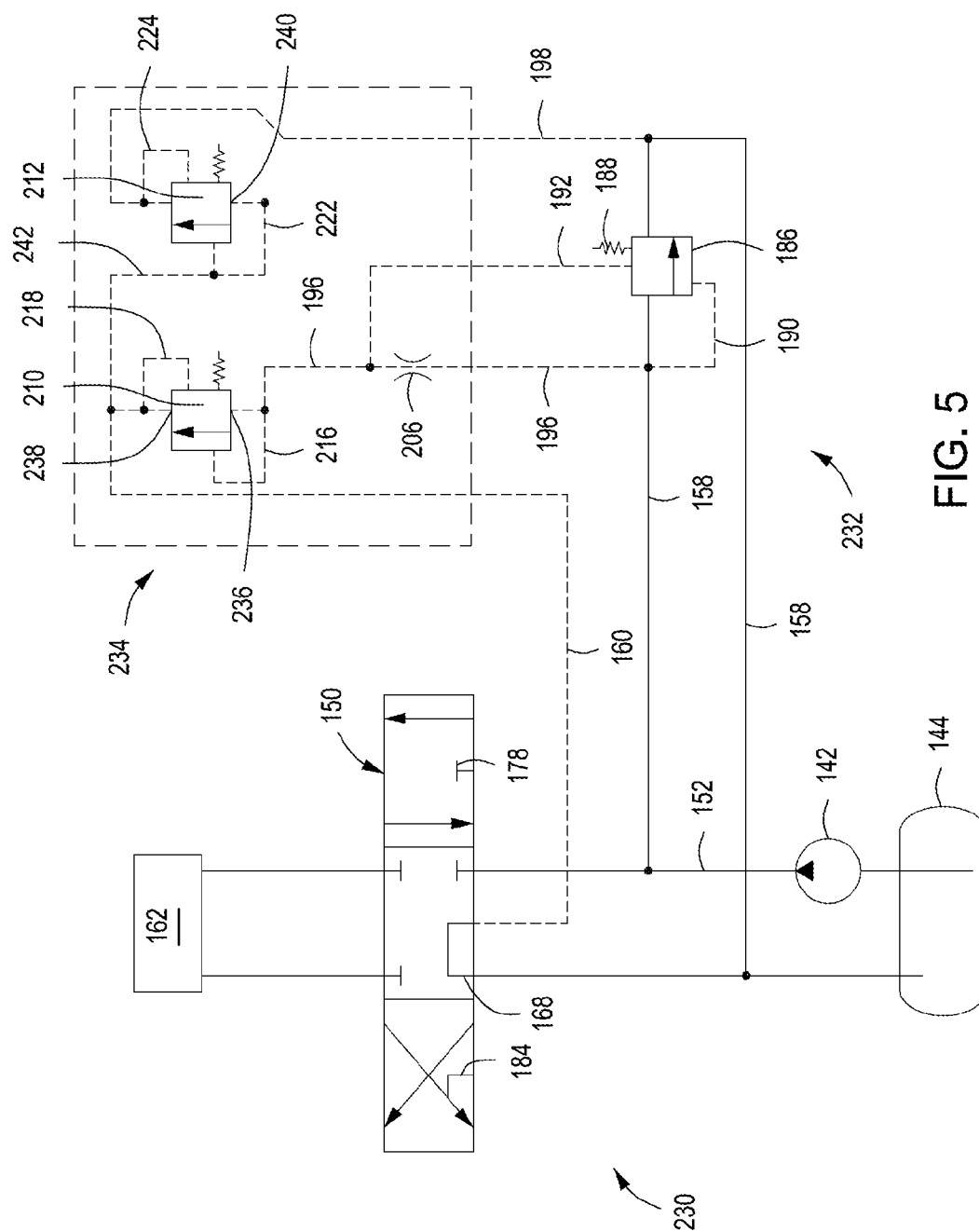


FIG. 5

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CONTROL VALVE WITH VARIABLE PRESSURE RELIEF

TECHNICAL FIELD

The disclosure relates generally to hydraulic pressure control in a hydraulic system, and more particularly, to apparatuses and methods for controlling a hydraulic pressure system including a variable relief pressure setpoint.

BACKGROUND

Hydraulic systems are known for converting fluid energy, for example, fluid pressure, into mechanical energy. Fluid power may be transferred from a hydraulic pump through fluid conduits to one or more hydraulic actuators. Hydraulic actuators may include hydraulic motors that convert fluid power into shaft rotational power, hydraulic cylinders that convert fluid power into translational motion, or the like.

Some hydraulic systems include a plurality of hydraulic actuators. For example, lift trucks for transporting materials may include a hydraulic motor to propel one or more drive wheels of the lift truck, in addition to an array of hydraulic cylinders that perform different functions, such as, for example, lifting a load against gravity, adjusting an angular orientation of the load with respect to the lift truck, and adjusting a distance between lift forks. Similarly, off-highway trucks for mining and excavation operations may include, for example, hydraulic motors to propel drive wheels and steer the truck, in addition to hydraulic cylinders to raise and lower a bucket.

In such systems, separate hydraulic actuators may have significantly different power requirements; and therefore, different corresponding pressure requirements to optimize system operability and efficiency. For example, the fork distance adjustment cylinder in a lift truck may have significantly lower pressure requirements than the lift cylinder in the same truck because, unlike the lift cylinder, the fork adjustment cylinder only has to move the weight of the forks and not the weight of a load bearing on the forks.

U.S. Pat. No. 7,222,484 (hereinafter “the ‘484 patent”), entitled “Hydraulic System with Multiple Pressure Relief Valves,” purports to address the problem of various hydraulic pressure requirements in a hydraulic system. The ‘484 patent describes hydraulic systems in which various hydraulic actuators have different operating pressure limits as determined by separate pressure relief valves. However, incorporating multiple pressure relief valves into a hydraulic system can be disadvantageously expensive, bulky, and unreliable. Accordingly, there is a need for improved hydraulic system pressure controls.

SUMMARY

In one aspect, the disclosure describes a hydraulic system. The hydraulic system includes a pump fluidly coupled to a reservoir that contains hydraulic fluid, a control valve fluidly coupled to the pump, the control valve being selectively movable between at least two positions, a relief valve fluidly coupled to the pump via a relief conduit, the relief valve operable to flow hydraulic fluid from an outlet of the pump to the reservoir, and a variable pressure setpoint module fluidly coupled to the relief valve and the control valve, the variable pressure setpoint module being operable to open the relief valve in response to at least two pressure setpoints depending on a position of the control valve.

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The variable pressure setpoint module includes a first pilot valve in fluid communication with the pump via a control orifice, the first pilot valve operable to flow hydraulic fluid from the control orifice to the reservoir via an internal passage defined by the control valve when the control valve is oriented in a first position and when a pressure in the variable pressure setpoint module exceeds a first pressure, and a second pilot valve in fluid communication with the pump via the control orifice, the second pilot valve operable to flow hydraulic fluid from the control orifice to the reservoir via a second return conduit when the control valve is oriented in a second position that blocks fluid communication between the control orifice and the reservoir via the control valve and when the pressure in the variable pressure setpoint module exceeds a second pressure, the second pressure being greater than the first pressure.

In another aspect, the disclosure describes a method of controlling hydraulic pressure. The method of controlling hydraulic pressure includes effecting a first pressure drop across a control orifice by flowing a first portion of hydraulic fluid from the control orifice to a reservoir via a first pilot valve, flowing a second portion of hydraulic fluid from a hydraulic pump to the reservoir via a relief valve by opening the relief valve in response to the first pressure drop across the control orifice, effecting a second pressure drop across the control orifice by flowing a third portion of hydraulic fluid from the control orifice to the reservoir via a second pilot valve, and flowing a fourth portion of hydraulic fluid from the hydraulic pump to the reservoir via the relief valve by opening the relief valve in response to the second pressure drop across the control orifice.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a side view of a truck having a hydraulic system according to an aspect of the disclosure.

FIG. 2 shows a front view of the truck illustrated in FIG. 1.

FIG. 3 shows a schematic view of a hydraulic system according to an aspect of the disclosure.

FIG. 4 shows a schematic view of a hydraulic system according to another aspect of the disclosure.

FIG. 5 shows a schematic view of a hydraulic system according to yet another aspect of the disclosure.

DETAILED DESCRIPTION

Referring now to the drawings, wherein like reference numbers refer to like elements, there is illustrated a machine including a hydraulic system. The machine can be any type of machine that performs an operation associated with an industry such as mining, construction, agriculture, transportation, or any other industry known in the art. For example, the machine may be an off-highway truck, an earth-moving machine, such as a wheel loader, excavator, dump truck, backhoe, motor grader, material handler, or the like. The specific machine illustrated in FIG. 1 is an off-highway dump truck.

Referring to FIGS. 1 and 2, it will be appreciated that FIG. 1 shows a side view of a truck 100 having a hydraulic system 102 according to an aspect of the disclosure; and FIG. 2 shows a front view of the truck illustrated in FIG. 1. Truck 100 includes a chassis 104, which may support various drive system components. The drive system components may include at least one drive wheel 106 and at least one idle wheel 108 rotatably coupled to the chassis 104. The at least one drive wheel 106 may be operably coupled to a hydraulic drive motor (not shown) or a transmission extending from a com-

bustion engine, electric motor, or other prime mover known to persons with ordinary skill in the art (not shown). The at least one idle wheel **108** may be operably coupled to a hydraulic steering motor (not shown) to steer the direction of the at least one idle wheel with respect to the chassis **104**. Although the truck **100** may include a rigid chassis, it may alternatively include an articulated chassis.

The truck **100** includes at least one hydraulic actuator **110** as part of a hydraulic system **102**. The hydraulic actuator **110** may be a hydraulic cylinder extending from a pivoting connection **112** on the chassis to a pivoting connection **114** on a bucket **116**. The bucket **116** may be pivotally coupled to the chassis **104** at a bucket pivot (not shown), and arranged to carry a payload when the truck **100** is in service. It will be appreciated that the hydraulic actuator **110** could be any hydraulic actuator arranged to serve functions known to persons of ordinary skill in the art.

The truck **100** may include a cab **118** configured to accommodate an operator and which may provide operator access to control inputs devices (not shown) such as hydraulic control valves located therein. Further, the truck **100** may include a power system enclosure **120** that houses one or more power sources (not shown) such as, for example, a combustion turbine engine, a reciprocating combustion engine, a fuel cell, a battery, a capacitor, or other power source known to persons having ordinary skill in the art. The one or more power sources may be operatively coupled to a hydraulic pump (not shown) that is fluidly coupled to the hydraulic system **102**.

FIG. 3 shows a schematic view of a hydraulic system **140** according to an aspect of the disclosure. The hydraulic system **140** includes a pump **142** coupled to a reservoir **144** that is filled with hydraulic fluid. Hydraulic fluid from the reservoir **144** is drawn into an inlet **146** of the pump **142** and discharged at a higher pressure from an outlet **148** of the pump **142**. The pump **142** is fluidly coupled to a control valve **150** through a first power conduit **152**, and the reservoir **144** is fluidly coupled to the control valve **150** through a second power conduit **154**.

A pressure control system **156** may be fluidly coupled to the pump **142** through a relief conduit **158**, which continues downstream of the pressure control system **156** to the reservoir **144**. The pressure control system **156** also may be fluidly coupled to the control valve **150** through a first return conduit **160**.

In one aspect of the disclosure, the control valve **150** is fluidly coupled to a hydraulic actuator **162** through a first actuator conduit **164** and a second actuator conduit **166**; and the control valve **150** is movable between at least two positions, that may include up to five connections for each position, thereby effecting at least two different states of fluid communication through the control valve **150**. It will be appreciated that other arrangements are contemplated as well.

In a first position, as shown in FIG. 3, the control valve **150** effects fluid communication between the second power conduit **154** and the first return conduit **160** via an internal passage **168**. Further corresponding to the first position of the control valve **150**, the first power conduit **152**, the first actuator conduit **164**, and the second actuator conduit **166** are all blocked within the control valve **150** by blocking passages **170**, **172**, and **174**, respectively.

Accordingly, when the control valve **150** is in its first position, the pressure control system **156** is in fluid communication with the reservoir **144** via the internal passage **168** of the control valve **150**, and neither the pump **142** nor the reservoir **144** are in fluid communication with the hydraulic actuator **162**. The first position of the control valve **150** may

be known as a neutral position because it does not effect fluid communication between the pump **142** and the hydraulic actuator **162**.

The control valve **150** may be configured in a second position by translating the control valve **150** to the left from its position shown in FIG. 3 with respect to the hydraulic system **140**. In the second position, the control valve **150** effects fluid communication between the first power conduit **152** and the first actuator conduit **164** through the internal passage **174**, and effects fluid communication between the second power conduit **154** and the second actuator conduit **166** through the internal passage **176**. Further corresponding to the second position of the control valve **150**, the first return conduit **160** is blocked within the control valve **150** by the blocking passage **178**.

Accordingly, when the control valve **150** is configured in its second position, the pump **142** and the reservoir **144** are both in fluid communication with the hydraulic actuator **162**, and the pressure control system **156** is not in fluid communication with the reservoir **144** via the first return conduit **160**. When the hydraulic actuator **162** is a hydraulic cylinder, the second position of the control valve **150** may be known as a cylinder extending position because the hydraulic system **140** may act to extend the length of the hydraulic cylinder by increasing a pressure within the hydraulic cylinder, such as, for example, a hoist function for the bucket **116** of the truck **100** (see FIG. 1).

The control valve **150** may be configured in a third position by translating the control valve **150** to the right from its position shown in FIG. 3 with respect to the hydraulic system **140**. In the third position, the control valve **150** effects fluid communication between the first power conduit **152** and the second actuator conduit **166** through the internal passage **180**, and effects fluid communication between the second power conduit **154** and the first actuator conduit **164** through the internal passage **182**. Further corresponding to the third position of the control valve **150**, the first return conduit **160** is in fluid communication with the reservoir **144** through the internal passage **184**.

Accordingly, when the control valve **150** is in its third position, the pump **142** and the reservoir **144** are both in fluid communication with the hydraulic actuator **162**, and the pressure control system **156** is in fluid communication with the reservoir **144** via the first return conduit **160**. When the hydraulic actuator **162** is a hydraulic cylinder, the third position of the control valve **150** may be known as a cylinder retracting position because the hydraulic system **140** may act to retract the length of the hydraulic cylinder by decreasing a pressure within the hydraulic cylinder, such as, for example, a lower function for the bucket **116** of the truck **100** (see FIG. 1).

Although the exemplary control valve **150** shown in FIG. 3 embodies three positions, with five connections per position, it will be appreciated that the control valve **150** could embody any number of positions and any number of connections per position. Further, the control valve **150** is not limited to the particular internal connections illustrated in FIG. 3, but rather, it will be appreciated that other control valve **150** internal connections could be employed without departing from the scope of the disclosure.

As shown in FIG. 3, the pressure control system **156** includes a relief valve **186** fluidly coupled to the pump **142** and the reservoir **144** via the relief conduit **158**. The relief valve **186** may be movable between two positions, where a first position blocks fluid communication between the pump **142** and the reservoir **144** via the relief conduit **158**, and a second position that effects fluid communication between the

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pump **142** and the reservoir **144** via the relief conduit **158**. The relief valve **186** may be configured to toggle between open and closed positions, or alternatively, respond proportionally to a control input. The fluid flow path through the relief conduit **158** and the relief valve **186** are designed to effect a large enough flow from the pump **142** to the reservoir **144** to reduce the fluid pressure in the first power conduit **152**.

The position of the relief valve **186** may be determined by a force balance across opposing sides of the relief valve **186**. The relief valve **186** may include a resilient member **188** that biases the relief valve toward a closed position. Alternatively, it will be appreciated that the resilient member could be arranged to bias the relief valve **186** toward an open position. Fluid pressure acting against the relief valve **186** from a first pilot conduit **190** and a second pilot conduit **192** may act to bias the relief valve **186** toward its open position and its closed position, respectively. Thus, in the non-limiting aspect illustrated in FIG. 3, the relief valve **186** remains closed as long as the combined force applied by the second pilot conduit **192** and the resilient member **188** is not less than the force applied by the first pilot conduit **190**.

The pressure control system **156** further includes a pressure setpoint module **194**, which may be in fluid communication with the relief valve **186** through a third pilot conduit **196** and the second pilot conduit **192**. The third pilot conduit **196** may be fluidly coupled to the relief conduit **158** upstream of the relief valve **186**, as shown in FIG. 3, or any other point in the hydraulic system **140** containing a pressure representative of the pump **142** discharge pressure. The pressure setpoint module **194** may also be fluidly coupled to the first return conduit **160** and a second return conduit **198**. It will be appreciated that the second return conduit **198** could be fluidly coupled to the reservoir **144** through the relief conduit **158**, downstream of the relief valve **186**, as shown in FIG. 3, or alternatively, the second return conduit **198** could extend to the reservoir **144** separate from the relief conduit **158** (not shown).

The pressure setpoint module **194** operates to vary the fluid pressure in the second pilot conduit **192** based on its state of fluid communication with other points in the hydraulic system **140**, a time history of fluid pressure within the pressure setpoint module **194**, or combinations thereof. In one aspect of the disclosure, the pressure setpoint module **194** may apply the same pressure to the second pilot conduit **192** as the first pilot conduit **190** when a pressure in the third pilot conduit **196** is less than a first threshold pressure, thereby maintaining the relief valve **186** in its closed position.

According to another aspect of the disclosure, when the pressure in the third pilot conduit **196** is not less than the first threshold pressure, the pressure setpoint module **194** may apply a pressure to the second pilot conduit **192** that is sufficiently lower than the pressure in the first pilot conduit **190** to overcome the force of the resilient member **188**, thereby opening the relief valve **186**. According to yet another aspect of the disclosure, the pressure setpoint module **194** may apply the same pressure to the second pilot conduit **192** as the first pilot conduit **190** when a pressure in the third pilot conduit **196** is less than a second threshold pressure, thereby maintaining the relief valve **186** in its closed position.

According to still yet another aspect of the disclosure, when the pressure in the third pilot conduit **196** is not less than the second threshold pressure, the pressure setpoint module **194** may apply a pressure to the second pilot conduit **192** that is sufficiently lower than the pressure in the first pilot conduit **190** to overcome the force of the resilient member **188**,

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thereby opening the relief valve **186**. Thus, the pressure setpoint module **194** may effect different pressure setpoints for opening the relief valve **186**.

The fluid resistance of the first pilot conduit **190**, the second pilot conduit **192**, the third pilot conduit **196**, and the pressure setpoint module **194** may be designed to be sufficiently small so that fluid communication between those flowpaths and the reservoir are not large enough to significantly affect fluid pressure in the first power conduit **152**. Throughout the drawings in the disclosure, fluid conduits indicated with dashed lines may be sized sufficiently small to accommodate only signal-level or pilot-level flows that do not significantly effect fluid pressure in the first power conduit **152** by themselves, without causing action of the relief valve **186**.

In one aspect of the disclosure, the first threshold pressure is less than the second threshold pressure. The first threshold pressure may be applied as the relief valve **186** opening setpoint pressure when the pressure setpoint module **194** is in fluid communication with the reservoir **144** via the first return conduit **160**. Further, the second threshold pressure may be applied as the relief valve **186** opening setpoint pressure when the pressure setpoint module **194** is blocked from fluid communication with the reservoir **144** via the first return conduit **160**.

FIG. 4 shows a schematic view of a hydraulic system **200** according to another aspect of the disclosure. Similar to the aspect shown in FIG. 3, the hydraulic system **200** may include a pump **142**, a reservoir **144**, a control valve **150**, and a hydraulic actuator **162**. However, the hydraulic system **200** includes a pressure control system **202** having a relief valve **186** fluidly coupled to a pressure setpoint module **204**.

The pressure setpoint module **204** includes a control orifice **206** that is in fluid communication with the relief conduit **158** via the third pilot conduit **196**. Further, the second pilot conduit **192** is fluidly coupled with the third pilot conduit **196** downstream of the control orifice **206**, opposite the relief conduit **158**. Thus, the difference in fluid pressure between the first pilot conduit **190** and the second pilot conduit **192**, and therefore the difference in fluid actuation pressure across the relief valve **186**, is equal to the pressure drop **208** across the control orifice **206**, neglecting any other fluid pressure drops through any of the pilot conduits.

As will be appreciated by those with ordinary skill in the art, a pressure drop **208** across the control orifice **206** can be generated by effecting a flow through the control orifice **206**. Thus, in the absence of fluid flow through the control orifice **206**, the pressure drop **208** across the control orifice **206** is substantially zero, and therefore the resilient member **188** maintains the relief valve **186** in a closed position to block fluid communication between the pump **142** and the reservoir **144** via the relief conduit **158**. On the other hand, a flow of sufficient magnitude from the relief conduit **158** through the control orifice **206** may create a sufficient pressure drop **208** to overcome the force of the resilient member **188** to actuate the relief valve **186** to an open position, thereby effecting fluid communication between the pump **142** and the reservoir **144** via the relief valve **186**.

The pressure setpoint module **204** further includes a first pilot valve **210** and a second pilot valve **212** in fluid communication with the relief conduit **158** via the control orifice **206**. According to an aspect of the disclosure shown in FIG. 4, both the first pilot valve **210** and the second pilot valve **212** are two position valves with two connections. However, it will be appreciated that the pilot valves **210**, **212** could embody any number of positions and connections per position.

A resilient member **214** biases the first pilot valve **210** toward a closed position that blocks fluid communication between the third pilot conduit **196** and the first return conduit **160** via the first pilot valve **210**. However, the first pilot valve **210** is operable to move to a second position when a pressure in the fourth pilot conduit **216** is sufficiently larger than a pressure in the fifth pilot conduit **218** to overcome the resilience of the resilient member **214**. Thus, the second position of the first pilot valve **210** is arranged to effect fluid communication between the third pilot conduit **196** and the first return conduit **160** via the first pilot valve **210**.

A threshold pressure across the first pilot valve **210** that is sufficient to open the first pilot valve **210** may be referred to as the pressure setpoint of the valve. The pressure setpoint of the first pilot valve **210** is a function of a spring rate of the resilient member **214** and the hydraulic areas exposed to the fluid pressures in the fourth pilot conduit **216** and the fifth pilot conduit **218**, respectively, among other design considerations. Further, when the pressure in the first return conduit **160** is substantially atmospheric pressure or reservoir **144** pressure, the first pilot valve **210** opens when a pressure in the fourth pilot conduit **216** exceeds the pressure setpoint of the first pilot valve **210**.

When the control valve **150** is oriented in a position such that the first return conduit **160** is in fluid communication with the reservoir **144** through either the internal passage **168** or the internal passage **184**, a pressure in the third pilot conduit **196** that exceeds the pressure setpoint of the first pilot valve **210** may open the first pilot valve **210**, thereby effecting a flow from the relief conduit **158** to the reservoir **144** via the control orifice **206**. Further, it will be appreciated that the flow through the control orifice **206** as a result of opening the first pilot valve **210** may cause a pressure drop **208** across the control orifice **206** sufficient to open the relief valve **186**. Thus, a pressure in the fourth pilot conduit **216** that exceeds the setpoint pressure of the first pilot valve **210** may cause the relief valve **186** to open, thereby relieving pressure from the relief conduit **158** to the reservoir **144**.

However, when the control valve **150** is oriented in a position such that the first return conduit **160** is blocked from fluid communication with the reservoir, for example, by the blocking passage **178**, a substantial fluid pressure may be trapped in the first return conduit **160**. In such a circumstance, fluid pressure retained in the first return conduit **160** may prevent the first pilot valve **210** from opening, even if the pressure in the fourth pilot conduit **216** exceeds the pressure setpoint for the first pilot valve **210**. This may occur when the pressure difference between the fourth pilot conduit **216** and the fifth pilot conduit **218** does not exceed the pressure setpoint for the first pilot valve **210**. But when the control valve **150** blocks fluid communication between the first return conduit **160** and the reservoir **144** via an internal passage of the control valve **150**, the second pilot valve **212** may still act to effect another pressure setpoint, as next discussed.

A resilient member **220** biases the second pilot valve **212** toward a closed position that blocks fluid communication between the third pilot conduit **196** and the reservoir **144** via the second pilot valve **212**. However, the second pilot valve **212** is operable to move to a second position when a pressure in the sixth pilot conduit **222** is sufficiently larger than a pressure in the seventh pilot conduit **224** to overcome the resilience of the resilient member **220**. Thus, the second position of the second pilot valve **212** may be arranged to effect fluid communication between the third pilot conduit **196** and the reservoir **144** via the second pilot valve **212**.

A threshold pressure across the second pilot valve **212** that is sufficient to open the second pilot valve **212** may be

referred to as the pressure setpoint of the second pilot valve **212**. The pressure setpoint of the second pilot valve **212** is a function of a spring rate of the resilient member **220** and the hydraulic areas exposed to the fluid pressures in the sixth pilot conduit **222** and the seventh pilot conduit **224**, respectively, among other design considerations. Further, when the pressure in the second return conduit **198** is substantially atmospheric pressure or reservoir **144** pressure, the second pilot valve **212** opens when a pressure in the sixth pilot conduit **222** exceeds the pressure setpoint of the second pilot valve **212**.

A pressure in the third pilot conduit **196** that exceeds the pressure setpoint of the second pilot valve **212** may open the second pilot valve **212**, thereby effecting a flow from the relief conduit **158** to the reservoir **144** via the control orifice **206**. Further, it will be appreciated that the flow through the control orifice **206** as a result of opening the second pilot valve **212** may cause a pressure drop **208** across the control orifice **206** sufficient to open the relief valve **186**. Thus, a pressure in the sixth pilot conduit **222** that exceeds the setpoint pressure of the second pilot valve **212** may cause the relief valve **186** to open, thereby relieving pressure from the relief conduit **158** to the reservoir **144**.

Accordingly, when the pressure setpoint of the first pilot valve **210** is lower than the pressure setpoint of the second pilot valve **212**, and the first return conduit **160** is in fluid communication with the reservoir **144** via an internal passage **168** of the control valve **150**, the relief valve **186** will be controlled substantially according to the pressure setpoint of the first pilot valve **210**. Further, when the first return conduit **160** is blocked from fluid communication with reservoir **144** through the control valve **150**, the relief valve **186** will be controlled substantially according to the pressure setpoint of the second pilot valve **212**, independent of the state of the first pilot valve **210**. Therefore, fluid interaction between the control valve **150** and the pressure setpoint module **204** enables variable pressure control setpoints for the relief valve **186** depending on the position of the control valve **150**.

FIG. 5 shows a schematic view of a hydraulic system **230** according to yet another aspect of the disclosure. Similar to the aspect shown in FIG. 3, the hydraulic system **230** may include a pump **142**, a reservoir **144**, a control valve **150**, and a hydraulic actuator **162**. However, the hydraulic system **230** includes a pressure control system **232** having a relief valve **186** fluidly coupled to a pressure setpoint module **234**. And similar to the aspect shown in FIG. 4, the pressure setpoint module **234** includes a first pilot valve **210** and a second pilot valve **212**, but the pilot valves **210**, **212** of the pressure setpoint module **234** are arranged with one another in series instead of in parallel, as discussed below.

Referring to FIG. 5, an inlet **236** of the first pilot valve **210** is fluidly coupled to the control orifice **206** via the third pilot conduit **196**. Further, an outlet **238** of the first pilot valve **210** is fluidly coupled to both the first return conduit **160** and an inlet **240** of the second pilot valve **212** via an eighth pilot conduit **242**.

When the control valve **150** is oriented in a position such that the first return conduit **160** is in fluid communication with the reservoir **144** through either the internal passage **168** or the internal passage **184**, for example, a pressure in the third pilot conduit **196** in excess of the pressure setpoint of the first pilot valve **210** may open the first pilot valve **210**, thereby effecting a flow from the relief conduit **158** to the reservoir **144** via the control orifice **206**. Further, it will be appreciated that the flow through the control orifice **206** as a result of opening the first pilot valve **210** may cause a pressure drop across the control orifice **206** sufficient to open the relief valve **186**. Thus, a pressure in the fourth pilot conduit **216** in excess

of the setpoint pressure of the first pilot valve **210** may cause the relief valve **186** to open, thereby relieving pressure from the first return conduit **160** to the reservoir **144**.

When the control valve **150** is oriented in a position such that the first return conduit **160** is blocked from fluid communication with the reservoir **144**, for example, by the blocking passage **178**, fluid may still flow through the pressure setpoint module **234** to the reservoir **144** via the first pilot valve **210**, the second pilot valve **212**, and the second return conduit **198**. In such a series configuration, a pressure in the third pilot conduit **196** must exceed the sum of the pressure setpoint of the first pilot valve **210** and the pressure setpoint of the second pilot valve **212** to simultaneously open both pilot valves **210**, **212**. In turn, a pressure in the third pilot conduit **196** in excess of the sum of the pressure setpoint of the first pilot valve **210** and the pressure setpoint of the second pilot valve **212** may effect a flow through the control orifice **206** sufficient to open the relief valve **186**.

Accordingly, when the pressure setpoint of the first pilot valve **210** is lower than the pressure setpoint of the second pilot valve **212**, and the first return conduit **160** is in fluid communication with the reservoir **144** via the control valve **150**, the relief valve **186** may be controlled substantially according to the pressure setpoint of the first pilot valve **210**. Further, when the first return conduit **160** is blocked from fluid communication with reservoir **144** via the blocking passage **178** of the control valve **150**, the relief valve **186** will be controlled substantially according to the sum of the pressure setpoint of the first pilot valve **210** and the pressure setpoint of the second pilot valve **212**. For example, to effect pressure relief setpoints of 2000 psi and 3000 psi according to the aspect shown in FIG. 5, the pressure setpoint of the first pilot valve would be approximately 2000 psi and the pressure setpoint of the second pilot valve **210** would be approximately 1000 psi. Therefore, fluid interaction between the control valve **150** and the pressure setpoint module **234** enables variable pressure control setpoints for the relief valve **186** depending on the position of the control valve **150**.

INDUSTRIAL APPLICABILITY

The disclosure is universally applicable to any machine with a hydraulic system. In particular, there are many types of off-highway vehicles associated with industries such as mining, construction, agriculture, transportation, and other industrial applications known to persons of ordinary skill in the art. The off-highway vehicle may be, for example, an earth-moving machine, such as a track type tractor, track loader, wheel loader, excavator, dump truck, backhoe, motor grader, a material handler, or the like.

In one configuration, as shown in FIG. 1, an operator located in the cab **118** may activate a control input device to the hydraulic system **102**, such as, for example, a control valve **150** (see FIG. 3), causing the hydraulic actuator **110** to either extend or retract in response changes in fluid pressure within the hydraulic actuator **110**. Extension of the hydraulic actuator **110** may rotate the bucket **116** about the bucket pivot in a first direction, away from the chassis **104**, to a dumping position for unloading the bucket payload. And retraction of the hydraulic actuator **110** may rotate the bucket **116** about the bucket pivot in a second direction to lower the bucket **116** to rest on the chassis **104** in a hauling position.

In one aspect, the hydraulic system **102** may benefit from a high pressure to raise the bucket **116**, and perhaps a payload disposed therein, to a dumping position by extending the hydraulic actuator **110**. In another aspect, the hydraulic sys-

tem **102** may benefit from a lower pressure to lower the bucket **116** during a power down function by retracting the hydraulic actuator **110**.

Referring to FIGS. 4 and 5, when the control valve **150** is in a neutral position, thereby blocking fluid communication between the hydraulic actuator **162** and the pump **142**, system energy efficiency and component life may benefit from a reduced pump **142** discharge pressure. Thus, it may be desirable to operate the relief valve **186** in response to a low pressure setpoint when the control valve **150** is in a neutral position. A low pressure setpoint for the relief valve **186** may be accomplished according to aspects of the disclosure by effecting fluid communication between the first return conduit **160** and the reservoir **144** through the internal passage **168** of the control valve **150**, as discussed above.

When the control valve **150** is adjusted to a cylinder extending function, thereby enabling fluid communication between the hydraulic actuator **162** and the pump **142**, system performance may benefit from an increased pump **142** output pressure to increase the hydraulic energy available to perform work using the hydraulic actuator **162**. One example of a cylinder extending function could include raising the bucket **116** on the truck **100**. Thus, it may be desirable to operate the relief valve **186** according to a high pressure setpoint when the control valve **150** is in a position corresponding to the cylinder extending function. A high pressure setpoint for the relief valve **186** may be accomplished according to aspects of the disclosure by blocking fluid communication between the first return conduit **160** and the reservoir **144** via the blocking passage **178** of the control valve **150**, as discussed above.

When the control valve **150** is in a cylinder retracting position, thereby enabling fluid communication between the hydraulic actuator **162** and the pump **142** to decrease a pressure in the hydraulic cylinder, system energy efficiency, component life, and safety may benefit from a reduced pump **142** discharge pressure. Thus, it may be desirable to operate the relief valve **186** according to the low pressure setpoint when the control valve **150** is in a cylinder retracting position. A low pressure setpoint for the relief valve **186** may be accomplished according to aspects of the disclosure by effecting fluid communication between the first return conduit **160** and the reservoir **144** through the internal passage **184** of the control valve **150**, as discussed above.

The ability to vary the pressure setpoint for relief valve operation using only one relief valve offers advantages over conventional approaches by decreasing system size, improving system reliability, and decreasing system cost. Further, aspects of the disclosure allow variation in pressure control setpoint for different operation modes of a single hydraulic actuator that are not achieved by conventional approaches.

Moreover, aspects of the disclosure allow a wider range of pressure setpoint variation than conventional approaches. For example, conventional approaches allow a high pressure setpoint that is only approximately 20-50% higher than a corresponding low setpoint. By contrast, aspects of the disclosure are capable of achieving wider ratios between a high pressure setpoint and a low pressure setpoint, including the ratios achieved by conventional approaches. For example, in one aspect, a hydraulic system benefits from a ratio of a high pressure setting to a low pressure setting not less than about 2:1. In another aspect, a hydraulic system with a different configuration benefits from a ratio of a high pressure setting to a low pressure setting not less than about 5:1.

As far as differences between pressure setpoints, in one aspect, a difference between a first pressure setpoint and a second pressure setpoint for the relief valve **186** could be greater than or equal to 1 psi. In another aspect, for a hydraulic

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system with another configuration, a difference between a first pressure setpoint and a second pressure setpoint for the relief valve could be greater than or equal to 20,000 psi. In yet another aspect, a hydraulic system with another configuration benefits from a low pressure setpoint not greater than about 500 psi and a high pressure setpoint not less than about 2750 psi for the relief valve **186**. In still yet another aspect, a hydraulic system with another configuration benefits from a low pressure setpoint not greater than about 1000 psi and a high pressure setpoint not less than about 5000 psi for the relief valve **186**.

Although the specific aspects disclosed herein describe apparatuses and methods for applying two pressure setpoints to the relief valve **186**, it will be appreciated that more than two pressure setpoints may be applied to the same relief valve without departing from the scope of the disclosure. In particular, any number of pilot valves may be added to the two pilot valves **210**, **212**, in parallel arrangement (see FIG. **4**) or series arrangement (see FIG. **5**), to effect a number of pressure setpoints greater than two. Further, a corresponding number of connections, positions, and internal or blocking passages may be added to the control valve **150** to control the logical sequencing of more than two pressure setpoints for the relief valve **186** according to aspects of the disclosure.

It will be appreciated that the foregoing description provides examples of the disclosed system and technique. However, it is contemplated that other implementations of the disclosure may differ in detail from the foregoing examples. All references to the disclosure or examples thereof are intended to reference the particular example being discussed at that point and are not intended to imply any limitation as to the scope of the disclosure more generally. All language of distinction and disparagement with respect to certain features is intended to indicate a lack of preference for those features, but not to exclude such from the scope of the disclosure entirely unless otherwise indicated.

Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context.

I claim:

1. A hydraulic system, comprising:

a pump fluidly coupled to a reservoir that contains hydraulic fluid;

a control valve fluidly coupled to the pump, the control valve being selectively movable between at least two positions;

a relief valve fluidly coupled to the pump via a relief conduit, the relief valve operable to flow hydraulic fluid from an outlet of the pump to the reservoir; and

a variable pressure setpoint module fluidly coupled to the relief valve and the control valve, the variable pressure setpoint module being operable to open the relief valve in response to at least two pressure setpoints depending on a position of the control valve, the variable pressure setpoint module including

a first pilot valve in fluid communication with the pump via a control orifice, the first pilot valve operable to flow hydraulic fluid from the control orifice to the reservoir via an internal passage defined by the control valve when the control valve is oriented in a first position and when

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a pressure in the variable pressure setpoint module exceeds a first pressure, and
a second pilot valve in fluid communication with the pump via the control orifice, the second pilot valve operable to flow hydraulic fluid from the control orifice to the reservoir via a second return conduit when the control valve is oriented in a second position that blocks fluid communication between the control orifice and the reservoir via the control valve and when the pressure in the variable pressure setpoint module exceeds a second pressure, the second pressure being greater than the first pressure.

2. The hydraulic system of claim **1**, wherein the first position of the control valve blocks fluid communication between the pump and a hydraulic actuator.

3. The hydraulic system of claim **1**, wherein the first position of the control valve effects fluid communication between the pump and a hydraulic actuator.

4. The hydraulic system of claim **1**, wherein the second position of the control valve effects fluid communication between the pump and a hydraulic actuator.

5. The hydraulic system of claim **1**, wherein a resilient member biases the relief valve toward a position that blocks fluid communication between the outlet of the pump and the reservoir via the relief conduit.

6. The hydraulic system of claim **1**, wherein a difference between the second pressure and the first pressure is not less than about 1 psi.

7. The hydraulic system of claim **6**, wherein a difference between the second pressure and the first pressure is not less than about 2250 psi.

8. The hydraulic system of claim **1**, wherein a ratio of the second pressure to the first pressure is not less than about 2.

9. The hydraulic system of claim **8**, wherein a ratio of the second pressure to the first pressure is not less than about 5.

10. The hydraulic system of claim **1**, wherein an inlet of the first pilot valve and an inlet of the second pilot valve are fluidly coupled to an exit of the control orifice, and

wherein an outlet of the first pilot valve and an outlet of the second pilot valve are fluidly coupled to the reservoir.

11. The hydraulic system of claim **1**, wherein an inlet of the first pilot valve is fluidly coupled to an outlet of the control orifice, and an outlet of the first pilot valve is fluidly coupled to an inlet of the second pilot valve.

12. The hydraulic system of claim **1**, wherein the pump is selectively in fluid communication with a hydraulic actuator through the control valve.

13. The hydraulic system of claim **12**, wherein the hydraulic actuator is a hydraulic cylinder coupled between a bucket and a chassis of a truck to hoist or lower the bucket.

14. The hydraulic system of claim **3**, wherein the first position of the control valve is operable to decrease a hydraulic pressure in the hydraulic actuator.

15. The hydraulic system of claim **4**, wherein the second position of the control valve is operable to increase a hydraulic pressure in the hydraulic actuator.

16. The hydraulic system of claim **1**, wherein the second pressure is approximately a pressure setpoint of the second pilot valve.

17. A machine, comprising:

a chassis;

a bucket pivotally coupled to the chassis;

a hydraulic cylinder pivotally coupled to the bucket and the chassis; and

a hydraulic system to control the hydraulic cylinder, the hydraulic system including:

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a pump fluidly coupled to a reservoir that contains hydraulic fluid;

a control valve fluidly coupled to the pump, the control valve being selectively movable between at least two positions;

a relief valve fluidly coupled to the pump via a relief conduit, the relief valve operable to flow hydraulic fluid from an outlet of the pump to the reservoir; and

a variable pressure setpoint module fluidly coupled to the relief valve and the control valve, the variable pressure setpoint module being operable to open the relief valve in response to at least two pressure setpoints depending on a position of the control valve, the variable pressure setpoint module including

a first pilot valve in fluid communication with the pump via a control orifice, the first pilot valve operable to flow hydraulic fluid from the control orifice to the reservoir via an internal passage defined by the control valve when the control valve is oriented in a first position and when a pressure in the variable pressure setpoint module exceeds a first pressure, and

a second pilot valve in fluid communication with the pump via the control orifice, the second pilot valve operable to flow hydraulic fluid from the control orifice to the reservoir via a second return conduit when the control valve is oriented in a second position that blocks fluid communication between the control orifice and the reservoir via the control valve and when the pressure in the variable pressure setpoint module exceeds a second pressure, the second pressure being greater than the first pressure.

18. A method of controlling hydraulic pressure, comprising:

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effecting a first pressure drop across a control orifice by flowing a first portion of hydraulic fluid from the control orifice to a reservoir via a first pilot valve;

flowing a second portion of hydraulic fluid from a hydraulic pump to the reservoir via a relief valve by opening the relief valve in response to the first pressure drop across the control orifice;

effecting a second pressure drop across the control orifice by flowing a third portion of hydraulic fluid from the control orifice to the reservoir via a second pilot valve; and

flowing a fourth portion of hydraulic fluid from the hydraulic pump to the reservoir via the relief valve by opening the relief valve in response to the second pressure drop across the control orifice.

19. The method of claim 18, further comprising:

effecting fluid communication between the first pilot valve and the reservoir via a control valve by adjusting the control valve to a first position;

opening the first pilot valve in response to a hydraulic pressure difference across the first pilot valve in excess of a first pressure setpoint;

blocking fluid communication between the first pilot valve and the reservoir via the control valve by adjusting the control valve to a second position; and

opening the second pilot valve in response to a hydraulic pressure difference across the second pilot valve in excess of a second pressure setpoint.

20. The method of claim 19, wherein the second pressure setpoint is greater than the first pressure setpoint.

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